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Measuring Species Diversity on Revegetated Surface Mines: An Evaluation of Techniques

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RESEARCH SUMMARY

This report reviews the three most commonly used techniques for measuring species diversity in plant communities: (1) diversity indices, (2) rank correlation tests, and (3) similarity indices. The author discusses the suitability of each technique for assessing species diversity on mined land and evaluates the most often used indices, test statistics, or coefficients of each technique. Applications of the Shannon-Weiner diversity index, Spearman's rank order correlation coefficient, Motyka and others' and Bray and Curtis' version of Sorensen's similarity index, and Spatz' version of Jaccard's index for assessing mined land species diversity are presented in the appendix.

Several constraints render diversity indices inappropriate for the assessment of mined land species diversity. They do not provide direct comparisons between two communities, nor do they distinguish differences in the species-specific apportionment of individuals among species (evenness). Rank correlation tests provide only a relative comparison of species or life form apportionment and do not directly evaluate differences in species or life form numbers or identities. Similarity coefficients provide direct comparisons of both richness and evenness and appear to be well-suited for evaluating mined land diversity.

Measuring Species Diversity on Revegetated Surface Mines: An Evaluation of Techniques

Jeanne C. Chambers

INTRODUCTION

The Surface Mining Control and Reclamation Act of 1977 requires establishment of "a diverse, effective, and permanent vegetative cover . . . capable of self-regeneration and plant succession" (PL 95-87.91 STAT 491, para. 19). Currently, species diversity must be evaluated on revegetated coal mined lands prior to bond release. Developing methods for assessing species diversity has proven difficult, primarily because technical and conceptual information is lacking.

The concept of species diversity and its relationship to mined lands must be understood before methods of measurement can be discussed. Species diversity is most often equated with Whittaker's (1972) definition of alpha diversity: the within-habitat or intracommunity diversity. Alpha diversity includes both species number (richness) and the manner in which importance is proportioned among species (evenness). The importance of a species is a measure of the species' biological activity and of the amount of the community's resources that the species uses (Whittaker 1972); it is usually derived from estimates of numbers (density), production, and cover. Because alpha diversity is a more precise term than species diversity, it will be used throughout this paper.

Mined land diversity has frequently been assessed simply as species richness. The justification for the use of species richness is exemplified by Peet's (1974) statement that "Direct species counts, while lacking theoretical elegance, provide one of the simplest, most practical, and most objective measures of species richness." Peet also stated that species counts convey no useful information about underlying community relationships. Two communities that have the same numbers of species can exhibit very different relationships of species importances. Peet (1974) suggested that comparing species richness between communities may be invalid unless it is assumed that the contributions of individual species to community functioning are similar. This assumption is seldom met in a comparison of a revegetated area to a reference area, or a premining community.

Intuitively, the ideal measure of alpha diversity would combine both species richness and species evenness. Although the two-component approach appears well-suited to the evaluation of alpha diversity it is not a flawless method; Pielou stated that:

> It is futile to debate whether the loss in information that results from combining (or "confounding") these two properties is offset by the gain in simplicity resulting from use of a single index. Obviously there is no answer to this question; it must always depend on the reason for which diversity indices and measures of evenness were calculated in the first place, that is, on the nature of the underlying ecological problem whatever it may be.

Numerous measures of alpha diversity that combine both richness and evenness have been devised, but many are not applicable for evaluating revegetated mined lands. Because the standard used to assess the alpha diversity of revegetated mined land is usually the premining community or a reference area, measures selected for the evaluation must be suitable for direct comparisons between two communities. The selection of an appropriate diversity measure or measures is crucial in obtaining a valid assessment of alpha diversity.

Measurements of alpha diversity can be placed into three general categories: (1) diversity indices, (2) rank correlation tests, and (3) similarity indices. Each of the three will be reviewed and the applicability of each measure to the assessment of mined land alpha diversity will be discussed. Appendixes I, II, and III give sample calculations of the most frequently used index of each of the three types of measurements. Because the choice of an importance measure can greatly affect the final value of the index, appendix IV discusses the selection of importance measures.

DIVERSITY INDICES

Diversity indices are by far the most frequently used measures of alpha diversity. They can be subdivided into two major categories: dominance indices and information theory indices. Although numerous diversity indices exist, the most commonly used are variations of four basic indices: Simpson's index, McIntosh's index, Shannon-Weiner's index, and Brillouin's index. Each of the four will be reviewed and then the assumptions and constraints associated with the entire group will be discussed.

Simpson's and McIntosh's Indices

Simpson's index is a dominance index that measures the probability that two individuals selected at random from a sample will belong to the same species (Simpson 1949). In its simplest form, the calculation for an infinite sample is:

$$\text{Simpson } \lambda = \sum_{i=1}^{s} p_i^2$$

where p_i is the proportion of the individuals in species i. Because this formulation varies inversely with alpha diversity, Greenburg (1956) and Berger and Parker (1970) have suggested subtracting the Simpson index from its maximum possible value of one. Therefore, the inverse or the complement value of the formulation above is usually used as a diversity index.

Figure 1 shows the response curve for this index. Indices of this type are termed dominance indices because divergence of species importance values consistently results in an increase in the index value (Peet 1974). This means that the index emphasizes the more common species in the community.

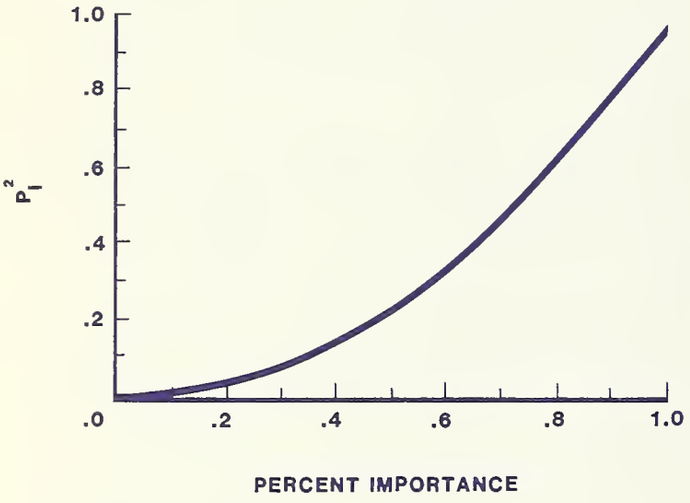

Figure 1.—The response curve of a dominance index represented by the Simpson index (from Peet 1974).

McIntosh (1967) has proposed a dominance index similar to that of Simpson's based upon a distance measure of the ecological similarity between samples. A stand can be thought of as a point in an n-dimensional hyperspace where each dimension refers to the abundance of a particular species. The similarity between stands is determined by the magnitude of the calculated distance values. The value for a single point in the n-dimensional hyperspace is defined as:

$$\sqrt{\sum_{i=1}^{s} n_i^2}$$

where n = the number of individuals of a single species and s is the number of species. The index in its final form expresses the observed diversity as a proportion of the absolute maximum diversity for a given sample size (N):

$$\text{McIntosh } N \quad \frac{\sqrt{\sum_{i=1}^{s} n_i^2}}{N - \sqrt{N}}$$

If percentage importance is to be used instead of numbers of individuals, the index becomes:

$$\text{McIntosh } 1 - \quad \sqrt{(\sum_{i=1}^{s} p_i^2)}$$

This index then has the same properties of dominance as Simpson's index.

The Shannon-Weiner and Brillouin Indices

Both the Shannon-Weiner index and the Brillouin index are referred to as information theory indices (Peet 1974). Pielou (1966) has explained the connection of information theory with the measurement of species diversity, stating that alpha diversity ". . . means the degree of uncertainty attached to the specific identity of any randomly selected individual. The greater the number of species and the more nearly equal their proportions, the greater the uncertainty and hence the diversity." She suggested that because information content is a measure of uncertainty, it is a valid measure of diversity.

The Shannon-Weiner index gives the information content per individual within an infinite population:

$$\text{Shannon-Weiner } H' = -\sum_{i=1}^{s} p_i \log p_i$$

where p_i is the percentage importance. A finite population can be described using the Brillouin formula:

$$\text{Brillouin } H = \frac{1}{N} \log \frac{N!}{N_1!\, N_2! \ldots N_s!}$$

where N is the total number of individuals, s the number of species, and N_i the number of individuals in the ith species. The base of the logarithm used determines the units in which diversity is measured, but does not alter the results.

The response curve shown in figure 2 illustrates that the Shannon-Weiner index is most sensitive to changes in those species that exhibit a relative importance of about 20 to 50 percent. The majority of the information theory indices, including the Brillouin index, exhibit this type of response curve.

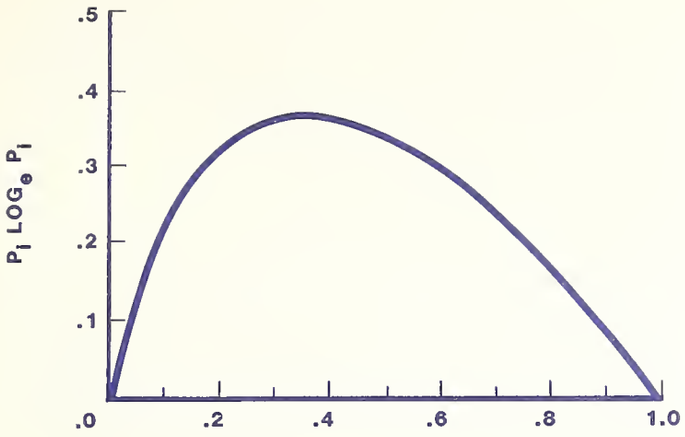

Figure 2.—The response curve of an importance index, represented by the Shannon-Weiner index (from Peet 1974).

Evaluation

Diversity indices, in general, are currently very popular measures of diversity and have often been assumed to provide "absolute" measures of diversity regardless of the type of importance value used or the kinds of communities investigated. Certain of the properties inherent in diversity indices, however, appear to render them inappropriate for the evaluation of mined land diversity. For example:

1. In general, diversity indices were devised for use with numbers of individuals and assume that all individuals are equal to one another (Pielou 1974). This is obviously not the case when dealing with such varied life forms as trees and grasses or forbs and shrubs and in practice, importance values are often substituted for numbers of individuals.

2. Diversity indices are statistically comparable only if based upon numbers of individuals (Lyons 1981; Pielou 1966) and even then, their comparability is questionable. Pielou (1966) suggests an estimate of variance based upon the usual sample variances of adjusted differences between values of H obtained from independent subsamples. A statistical technique proposed by Lyons (1981) uses importance values to assign a fixed weight to every individual of a species. Neither method has been validated.

3. It is difficult to compare values obtained from two different communities using certain diversity indices because a change in the index at one end of the scale is not necessarily proportionate to the same amount of change at the other end (see the response curves in figs. 1 and 2). Thus, index values obtained from different communities are not directly comparable, and individual index values cannot be reapportioned to 100 percent as suggested by Bonham and Larsen (1980) for the Shannon-Weiner index.

4. When examining two different communities, diversity indices do not reveal changes in the apportionment of individuals among species or in the identity of species (Peet 1974). For example, a reference area might have species A, B, C, D, and the apportionment of individuals might be 10, 2, 2, 1, respectively. If the revegetated area had the same species, A, B, C, D, but the apportionment of individuals was reversed, 1, 2, 2, 10, the diversity indices would still be the same for both areas. A completely different set of four species on the reclaimed area with the same set of apportionment values would also yield an identical index, although the reclaimed community would definitely be "different" than the reference community.

5. All diversity indices that contain a term for species number are said to be relativized. They are sample-size-dependent and two populations are comparable by these measures only when the sample sizes are identical (Peet 1975).

The value of diversity indices in assessing vegetation on surface mines has been mentioned (Wali 1980; Sindelar 1980), but concrete results have not been published. The State of Colorado at one time required certain mining companies to determine the diversity of reclaimed mined lands with the Shannon-Weiner index (Crofts 1981). In addition, Bonham and Larsen (1980) recommended that the Shannon-Weiner index be used to assess mined land diversity on all reclaimed mined lands administered by Region IV of the Office of Surface Mining (OSM). Given the constraints and assumptions previously listed, use of the Shannon-Weiner index as a sole criterion of diversity is not warranted. It is particularly inappropriate because it cannot describe the specific apportionment of importance among species between two areas, such as a revegetated and a reference area.

RANK CORRELATION TESTS

A direct, statistical measure of the values reflecting species importance (production, cover, or density) between reference and revegetated areas would appear to be a logical method for assessing diversity. Spearman's rank correlation coefficient provides a nonparametric statistical measure of the similarity between the two areas, as reflected by the relative importance of the various species or life forms within the two areas. The coefficient is based on the differences between the rank of each of the species or life forms that exist in the two areas; where the ranks are given the values of 1 for the most abundant species; 2 for the second most abundant species, etc. A rank correlation coefficient of 0 would suggest complete independence between the rankings of the two areas (no correspondence between the species that are most abundant in the revegetated area). A coefficient of 1 would indicate a perfect correspondence.

Spearman's rank order correlation coefficient is one of several such coefficients based on ranks. Its computation is explained in many statistics texts (Sokal and Rohlf 1969; Snedecor and Cochran 1967). Spearman's Rho, as this coefficient is sometimes called, assigns greater weights to those species or life form pairs that demonstrate large differences, than do some other rank correlation coefficients (Kentall's Tau). A test to determine whether Rho is greater than 0 is presented in appendix II.

The use of rank correlation tests for assessing mined land diversity is limited because of the following constraints:

1. Rank correlation tests provide only a relative comparison of species or life form apportionment, because ranking values are used instead of actual importance measures.

2. Tests of independence between two different areas do not directly evaluate differences in species or life form numbers or identities. Although provisions can be made for unequal numbers of species or life forms through "tie-breaking" procedures, large differences in species or life form composition between the two areas greatly decreases the validity of the test.

SIMILARITY INDICES

Similarity indices provide mathematical expressions for the similarity of communities (Mueller-Dombois and Ellenberg 1974). Such indices have been variously referred to as community coefficients and overlap indices. Historically, similarity indices have been used for the ordination of plant communities. Depending upon the type of index, the inputs are in the form of binary presence-absence data or importance values (often relativized). Similarity coefficients are scaled from 0 or −1 (no overlap in the distributions of observations among categories) to 1 (identical distributions). Dissimilarity coefficients are scaled from 0 to 1 or infinity, with 0 as maximum similarity. Because similarity indices can provide a simple mathematical comparison of the richness or richness and evenness (heterogeneity) of two communities, such as a revegetated and reference community, they seem particularly promising for the evaluation of mined land diversity.

Like diversity indices, similarity indices can be divided into several different classes: (1) those that require only an enumeration of the different resource states or presence-absence data, (2) indices that are based upon distance measurements, (3) indices that utilize information theory, and (4) indices derived from probability functions. The most commonly used indices in each class will be reviewed and recent comparisons of individual indices will be discussed.

Indices that Use Presence-Absence Data

The simplest indices are those that require only presence-absence data. They are, in general, a function of the number of plant species or life forms found in both communities as well as the number found in only one community or the other. Romesburg (personal communication) and Marshall and Romesburg (1979) described most commonly used indices and explained their application. Janson and Vegelius (1981) examined 20 indices of this type using 6 different criteria to determine the value of each index for measuring the degree of coexistence between two species over different localities. They concluded that only three indices, Ochiai's coefficient, r_o (1957), Dice's coefficient, r_d (1945), and Jaccard's coefficient, r_j (1908), met all six of their criteria. The formulas for these three indices are as follows:

$$\text{Ochiai } R_o = \frac{A}{\sqrt{A + B} \cdot \sqrt{A + C}}$$

$$\text{Dice } R_d = \frac{2 \cdot A}{2 \cdot A + B + C}$$

$$\text{Jaccard } R_j = \frac{A}{A + B + C}$$

When two species, s_1 and s_2, are being compared, A = the occurrence of both species, B = the occurrence of species s_1, and C = the occurrence of species s_2. These three indices are of value for the assessment of species diversity on mined lands only if a comparison of species numbers or richness is desired.

Indices that Include Importance Values

Similarity indices not included in Janson and Vegelius' (1980) study that incorporate the importance value of each species or life form are Motyka and others' (1950) and Bray and Curtis' (1957) version of Sorensen's index and Spatz' (1970) version of Jaccard's index. Bray and Curtis' version of Sorensen's similarity index is merely a computational simplification of Motyka and others' version that requires the use of percentage values for each species or life forms. Because these indices allow a direct comparison of two communities and are combined measures of richness and evenness, they may apply to the assessment of alpha diversity on mined lands.

Motyka's version of Sorensen's similarity index (IS_{mo}) is:

$$IS_{mo} = \frac{2\,MW}{MA + MB} \times 100$$

where MW = the sum of the smaller importance values of the species or life forms common to both areas, MA = the sum of the importance values of all species or life forms in one area, and MB = the sum of the importance values of all species or life forms in a second area.

Bray and Curtis' version of Sorensen's similarity index is as follows:

$$IS_{BC} = \frac{2MW}{200} \times 100 \text{ or } IS_{BC} = MW(\text{percent})$$

where MW = the sum of the smaller importance values of the species or life forms common to both areas.

Spatz' modification of Jaccard's index is slightly different than the two previous indices:

$$IS_{SP} = R \times \frac{MC}{MA + MB + MC} \times 100$$

where R = the smaller values of the species or life forms common to both areas divided by the greater values; the fractions are summed and the sum is divided by the total number of species in both areas. MC = the sum of the values of all species or life forms common to both areas, MA = the sum of the values of all species or life forms in one area, and MB = the sum of the values of all species or life forms in the second area. This index consists of two separate parts. The first part (R) expresses the relative similarity of the two areas being compared in terms of the number of common species

and the differences in importance values between individual species. The second part, the quantitative application of Jaccard's index examines the relative similarity of the two areas in terms of importance values.

The index value for each of these indices ranges from 0 to 1 with 1 being complete similarity. A comparison of the calculation of the three indices is presented in appendix III.

Indices Derived from Distance Measurements, Information Theory, and Probability Functions

The other types of similarity indices have recently been compared by Linton and others (1981) and Ricklefs and Lau (1980). Examples of the most frequently used indices of each type will be given and comparisons of the relative merits of each as described in the above studies will be discussed.

Two frequently used distance measurements are the Euclidean distance and Schoener's index (Schoener 1968). The formula for the two indices are:

$$\text{Euclidean distance} \quad E_{jk} = \left[\sum_{i=1}^{n} (x_{ij} - x_{ik})^2 \right]^{1/2}$$

$$\text{Average Euclidean distance} \quad D_{jk} = \left[\sum_{i=1}^{n} (x_{ij} - x_{ik})^2 / n \right]^{1/2},$$

$$\text{Schoener} \quad R_{ij} = 1 - \tfrac{1}{2} \sum |p_{ij} - p_{ik}|$$

where p = importance values from measurements of populations j and k in category i. This terminology will be applied throughout the remainder of the discussion.

Horn (1966) devised a similarity index based upon information theory:

$$\text{Horn } R_{ij} = [\Sigma(P_{ij} + p_{ik}) \log (p_{ij}p_{ik}) - \Sigma p_{ij} \log p_{ij} - \Sigma p_{ik} \log p_{ik}]/2 \log 2$$

Indices based upon probability functions include those of Morisita (1959) and Pianka (1973).

$$\text{Morisita } R_{ij} = \frac{2\Sigma p_{ij} p_{ik}}{\Sigma p_{ij}^2 + \Sigma p_{ik}^2} \quad \text{(modified by Horn 1966)}$$

$$\text{Pianka } R_{ij} = \frac{\Sigma p_{ij} p_{ik}}{\Sigma p_{ij}^2 \; \Sigma p_{ik}^2}$$

Ricklefs and Lau (1980) compared Morisita's and Horn's indices and the Euclidean distance, Linton and others (1981) evaluated differences in Schoener's, Horn's, Pianka's, and Morisita's (as modified by Horn 1966) indices. The results of these comparisons were:

1. For all indices, estimates of overlap increased with sample size. Linton and others (1981) found that estimated overlap leveled out at about 16 observations per population.

2. Pianka's and Horn's modification of Morisita's index produced identical results (Linton and others 1981).

3. Linton and others (1981) showed that only Schoener's index estimated overlap correctly when real overlap was between 7 and 85 percent. Similarly, Ricklefs and Lau (1980) found the standard deviations of samples of indices they tested to be greatest when expected overlap was intermediate between 0 and 1.

4. All four indices examined by Linton and others (1981) had similar accuracy with overlaps between 85 to 90 percent, but at higher overlaps, Schoener's index was least accurate.

5. When overlaps were below 7 percent, Schoener's and Horn's indices performed erratically and Morisita's and Pianka's indices were 70 percent below the actual overlap (Linton and others 1981).

In general, similarity indices based upon distance measurements, information theory, and probability measurements are most accurate at intermediate levels of overlap or similarity and are inconsistent at either high or low levels of overlap. Because the majority of these indices do not provide correct estimates of real overlap, their utility for assessing mined land alpha diversity appears limited. A possible exception may be Schoener's index when overlaps are not expected to be below 7 percent or above 85 percent.

Evaluation

The value of similarity indices for the assessment of mined land alpha diversity has not yet been tested. If species number is a criterion for successful revegetation, the three coefficients recommended in Janson and Vegelius' (1981) study, Ochiai's coefficient, Dice's coefficient and Jaccard's coefficient seem well-suited for the assessment of species numbers or richness. If it is desirable to evaluate both species richness and evenness, Motyka and others' (1950) and Bray and Curtis' (1957) version of Sorensen's index and/or Spatz' (1970) version of Jaccard's index have particularly good potential for the comparison of two communities. Chambers and Brown (1982) recommended their use for evaluating alpha diversity on revegetated mined lands in OSM Region IV.

The selection of Spatz' index or one of Sorensen's modifications would ultimately depend upon the objectives of the investigator. The general form of Sorensen's similarity index has been endorsed by Steward (1982) but Dr. Ed DePuit (personal communication) suggests the Spatz' index may provide a more reliable comparison of reference and revegetated areas.

The two types of indices place different emphasize on the quantitative and qualitative properties of revegetated and reference areas. In general, Spatz' index combines both quantitative and qualitative properties while Sorensen's modifications are more strictly quantitative (Mueller-Dombois and Ellenberg 1974). For example, Spatz' index places a greater emphasis on the comparison of the number of common and different species or life forms and the differences in importance values between individual species or life forms. Comparisons of revegetated and reference areas with several common species or life forms in which all of the common species or life forms have large importance values generally produce high similarity values when modifications of Sorensen's index are used. However, if the same areas also have species or life forms with smaller importance values that occur in only one or the other of the

areas, Spatz' index will produce a much smaller similarity value than Sorensen's modifications. The differences between these indices are illustrated in appendix III.

Because similarity indices furnish a single index value, their use would require the establishment of criteria for the determination of a "good" index value. Even the comparison of two highly similar communities often results in index values substantially lower than 1 (complete similarity). The index value obtained could be expected to vary according to the vegetation types under investigation. One method of obtaining a realistic "acceptable" index value would be to sample replicate areas within the reference area and to compute the similarity index for the replicates. This value would express the inherent similarity within the reference area. A value slightly lower than the one calculated for the reference area could then serve as the minimum similarity value for comparing the reference area to the revegetated area. Steward (1982) suggested that if several replicates were sampled within the reference area, similarity indices could be calculated between each of the replicates. A confidence interval could then be derived for the calculated similarity indices. The criterion for adequate alpha diversity would be that the similarity index calculated between the mean species or life form values of the reference and revegetated areas fall within the confidence interval calculated for the replicates.

CONCLUSIONS

A system of measurement used to compare the alpha diversity of a revegetated area to that of a reference area should include these attributes:

1. A "good" diversity measure should allow the direct comparison of two different communities—a reference area and a revegetated area. Ideally, the measure would produce only a single index.
2. The measure should be sensitive to changes in species or life form identities, and to species or life form importance values.
3. The measure should be equally effective with either life form or species data and adaptable to different types of importance measures (standing crop or cover).
4. A means of developing a standard of comparison for the measure should exist. For example, computing a similarity index from replicate samples within a reference area(s) provides an indication of the inherent similarity within the reference area that can be used as a standard of comparison for the revegetated area.
5. The measure should be easy to compute and understand.

Of the different types of diversity measures examined, only Motyka and others' and Bray and Curtis' version of Sorensen's and Spatz' version of Jaccard's index have all of the necessary properties. Diversity indices, in general, have several characteristics that are undesirable for evaluating mined land. The greatest limitation of diversity indices is that they cannot describe the specific apportionment of importance among species between two areas. Rank correlation tests appear to meet most of the criteria, however, they have certain restrictions that limit their use for evaluating mined land diversity. They provide only a relative comparison of species or life form apportionment and do not directly evaluate differences in species or life form identities.

Similarity indices, such as Motyka and others' and Bray and Curtis' version of Sorensen's index and Spatz' version of Jaccard's index have not received rigorous field tests, but conceptually, they are well suited for assessing mined land alpha diversity. Because they allow the sequential comparison of numerous different communities, namely, through cluster analysis, they can be used to synthesize information gathered from several different reference and revegetated areas, or information gathered on the same site over a period of time. They have excellent potential for developing idealized standards for particular community types, range sites, or habitat types within defined ecosystems.

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APPENDIX I. SAMPLE CALCULATION OF THE SHANNON DIVERSITY INDEX

A sample calculation for the Shannon index is given in table 1. The importance value used is dry weight production and the percentage of the importance value, p_i, is the percent production of each species or life form of the total production. Since the maximum value of H′ is equal to one, the H′ values obtained here, 0.872 for the revegetated area and 0.969 for the reference area, are actually very high. If it can be assumed that the calculated H′ value accurately depicts the diversity of the reference area, then the H′ value of the revegetated area would have to be within a certain limit of the reference area H′ in order to meet the diversity criteria. In interpreting and in calculating diversity indices, however, the constraints listed under the section on alpha diversity measures must be considered.

Table 1.—*A sample calculation of the Shannon index (lbs/acre = dry weight)*

Life form	Revegetated area			Reference area		
or species	lbs/acre	p_i	$-(p_i \log p_i)$	lbs/acre	p_i	$-(p_i \log p_i)$
1	553	0.200	0.140	524	0.177	0.133
2	479	0.173	0.132	348	0.117	0.109
3	234	0.084	0.090	441	0.149	0.123
4	625	0.226	0.146	563	0.190	0.137
5	351	0.127	0.114	197	0.066	0.078
6	26	0.009	0.018	151	0.051	0.066
7	108	0.039	0.055	94	0.032	0.048
8	84	0.030	0.046	175	0.059	0.073
9	67	0.025	0.039			
10	242	0.087	0.092			
11				269	0.091	0.095
12				43	0.014	0.026
13				123	0.042	0.058
14				36	0.012	0.023
Σ	2769	1.000	0.872	2964	1.000	0.969

APPENDIX II. TEST STATISTIC FOR SPEARMAN'S RANK CORRELATION COEFFICIENT—R_o AND A SAMPLE CALCULATION

The test statistic for Spearman's R_o, Spearman's R_s, is defined by the expression:

$$R_s = 1 - \frac{6\Sigma d_i^2}{n(n^2 - 1)}$$

where:

d_i = the difference between the two ranks
n = the number of comparisons

The null hypothesis that we wish to test is that the species or life form importance values of the revegetated and reference areas are not independent of each other. (The importance values for the two areas are apportioned between the species or life forms in the same manner.) For a one-sided test of the null hypothesis:

Accept H_o if $R_s \leq R_o$
Reject H_o if $R_s > R_o$

The critical values of Spearman's rank correlation coefficient, the R_o values, are found in table 2.

An approximate t* value can also be calculated with which to test the null hypothesis. The t* value can be used in place of the critical R_o values for $n > 30$ and for probability levels other than those shown in table 2. For a one-sided test of the null hypothesis:

$$t^* = R_s\sqrt{(n-2)/(1-R_s^2)}$$

Table 2.—*Critical values of Spearman's rank correlation coefficient*

n	α = 0.10	α = 0.05	α = 0.02	α = 0.01
5	0.900	—	—	—
6	0.829	0.886	0.943	—
7	0.714	0.786	0.893	—
8	0.643	0.738	0.833	0.881
9	0.600	0.683	0.783	0.833
10	0.564	0.648	0.745	0.794
11	0.523	0.623	0.736	0.818
12	0.497	0.591	0.703	0.780
13	0.475	0.566	0.673	0.745
14	0.457	0.545	0.646	0.716
15	0.441	0.525	0.623	0.689
16	0.425	0.507	0.601	0.666
17	0.412	0.490	0.582	0.645
18	0.399	0.476	0.564	0.625
19	0.388	0.462	0.549	0.608
20	0.377	0.450	0.534	0.591
21	0.368	0.438	0.521	0.576
22	0.359	0.428	0.508	0.562
23	0.351	0.418	0.496	0.549
24	0.343	0.409	0.485	0.537
25	0.336	0.400	0.475	0.526
26	0.329	0.392	0.465	0.515
27	0.323	0.385	0.456	0.505
28	0.317	0.377	0.448	0.496
29	0.311	0.370	0.440	0.487
30	0.305	0.364	0.432	0.478

From Olds (1938).

The calculated t* value is compared with a value for the t_{n-2} obtained from a t-table for one-sided tests (refer to table 3).

Accept H_o if $t^* \leq t_{n-2}$

Reject H_o if $t^* > t_{n-2}$

An example of a comparison between a revegetated area and a reference area using Spearman's R_o is given in table 4. The species or life forms from each area are first ranked according to the magnitude of their importance values. If species or life forms exist in one area but not the other, they are assigned the average of the lowest possible rankings for the area in which they do not exist. For example, the revegetation area shown in table 4 was missing four species or life forms that existed in the reference area. The lowest possible rankings for the revegetated area would be 11, 12, 13, and 14. The average of these four values, 12.5, is assigned to the species or life forms that are missing in the revegetated area.

Table 3.—*t-Distribution values for values for various levels of n, or degrees of freedom, df, for a one-sided test*

	Probability of a larger value of t, sign considered								
df	0.25	0.2	0.15	0.1	0.05	0.25	0.01	0.005	0.0005
1	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657	636.619
2	.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	31.598
3	.765	.978	1.250	1.638	2.353	3.182	4.541	5.841	12.941
4	.741	.941	1.190	1.533	2.132	2.776	3.747	4.604	8.610
5	.727	.920	1.156	1.476	2.015	2.571	3.365	4.032	6.859
7	.711	.896	1.119	1.415	1.895	2.365	2.998	3.449	5.405
8	.706	.889	1.108	1.397	1.860	2.306	2.896	3.355	5.041
9	.703	.883	1.100	1.383	1.833	2.262	2.821	3.250	4.781
10	.700	.879	1.093	1.372	1.812	2.228	2.764	3.169	4.587
11	.697	.876	1.088	1.363	1.796	2.201	2.718	3.106	4.437
12	.695	.873	1.083	1.356	1.782	2.179	2.681	3.055	4.318
13	.694	.870	1.079	1.350	1.771	2.160	2.650	3.012	4.221
14	.692	.868	1.076	1.345	1.761	2.145	2.624	2.977	4.140
15	.691	.866	1.074	1.341	1.753	2.131	2.602	2.947	4.073
16	.690	.865	1.071	1.337	1.746	2.120	2.583	2.921	4.015
17	.689	.863	1.069	1.333	1.740	2.110	2.567	2.898	3.965
18	.688	.862	1.067	1.330	1.734	2.101	2.552	2.878	3.922
19	.688	.861	1.066	1.328	1.729	2.093	2.539	2.861	3.883
20	.687	.860	1.064	1.325	1.725	2.086	2.528	2.845	3.850
21	.686	.859	1.063	1.323	1.721	2.080	2.518	2.831	3.819
22	.686	.858	1.061	1.321	1.717	2.074	2.508	2.819	3.792
23	.685	.858	1.060	1.319	1.714	2.069	2.500	2.807	3.767
24	.685	.857	1.059	1.318	1.711	2.064	2.492	2.797	3.745
25	.684	.856	1.058	1.316	1.708	2.060	2.485	2.787	3.725
26	.684	.856	1.058	1.315	1.706	2.056	2.479	2.779	3.707
27	.684	.855	1.057	1.314	1.703	2.052	2.473	2.771	3.690
28	.683	.855	1.056	1.313	1.701	2.048	2.467	2.763	3.674
29	.683	.854	1.055	1.311	1.699	2.045	2.462	2.756	3.659
30	.683	.854	1.055	1.310	1.697	2.042	2.457	2.750	3.646
40	.681	.851	1.050	1.303	1.684	2.021	2.423	2.704	3.551
60	.679	.848	1.046	1.296	1.671	2.000	2.390	2.660	3.460
120	.677	.845	1.041	1.289	1.658	1.980	2.358	2.617	3.373
∞	.674	.842	1.036	1.282	1.645	1.960	2.326	2.576	3.291

Table 4.—*An example of ranked revegetated and reference areas A_1 and A_2, the difference between the two, d_i, and the difference squared, d_i^2 (lbs/acre = dry weight)*

Life form	Revegetated area		Reference area		d_i	d_i^2
or species	lbs/acre	A_1	lbs/acre	A_2		
1	553	2	524	2	0	0
2	479	3	348	4	-1	1
3	234	6	441	3	3	9
4	625	1	563	1	0	0
5	351	4	197	6	-2	4
6	26	10	151	8	2	4
7	108	7	94	10	-3	9
8	84	8	175	7	1	1
9	67	9		13.5	-4.5	20.25
10	242	5		13.5	-8.5	72.25
11		12.5	269	5	7.5	56.25
12		12.5	43	11	1.5	2.25
13		12.5	123	9	3.5	12.25
14		12.5	36	12	.5	0.25
Σ						191.50

The difference between the two ranks of species or life forms found in the two areas, d_i, is obtained by subtracting rank 1, A_1, from rank 2, A_2. The values of d_i are then squared and summed. Once these values have been obtained, the test statistic for Spearman's rank correlation is computed:

$$R_s = 1 - \frac{6\Sigma d_i^2}{n(n^2-1)}$$

$$= 1 - \frac{6(191.50)}{14(14^2 - 1)}$$

$$= 1 - \frac{1149}{2730}$$

$$= 1 - .421$$

$$= 0.579$$

The critical value for R_o with $n = 14$ and $\alpha = 0.10$ is 0.457 (see table 2). Since the test statistic, $R_s = 0.579$, is greater than the critical value, $R_o = 0.457$, the null hypothesis is rejected. The revegetated area presented in this example was independent of the reference area at $\alpha = 0.10$. According to this test, the importance values for the two areas were not apportioned in a similar manner.

A t* value can also be calculated with which to test the hypothesis:

$$t^* = R_s\sqrt{(n-2)/(1-R_s^2)}$$

$$= 0.579\ \sqrt{(14-2)/(1-0.579^2)}$$

$$= 2.459$$

Because the value for $t_{12}(.05)$, 1.782, is less than the calculated t* value, 2.459, the null hypothesis is again rejected.

APPENDIX III. COMPARISON OF THE CALCULATION OF MOTYKA AND OTHERS' (1950) AND BRAY AND CURTIS' (1957) VERSION OF SORENSEN'S INDEX AND SPATZ' (1970) VERSION OF JACCARD'S INDEX

Tables 5, 6, and 7 present examples of the calculation of the three different indices. The importance values used are standing crop values (lbs/acre dry weight). Table 5 illustrates the difference between common and unique species in a reference and revegetated area and shows how they are used to calculate Motyka and others' version of Sorensen's index. Tables 6 and 7 illustrate the calculation of the three different indices and the effect of differences in life form importance values.

Table 5.—*An example of the common and unique species of a revegetated and reference area and the calculation of Motyka and others' version of Sorensen's index (lbs/acre = dry weight)*

Species	Revegetated area (MA) lbs/acre	Common species (MA) lbs/acre	Common species (MB) lbs/acre	Reference area (MB) lbs/acre
1		553	524	
2		479	348	
3		234	441	
4		625	563	
5		351	197	
6		26	151	
7		108	94	
8		84	175	
9	67			
10	242			
11				269
12				43
13				123
14				36
Total	309			471

Calculation of Motyka and others' version of Sorensen's index.

$$IS_{MO} = \frac{2\,MW}{MA + MB}$$

$$MW = 524 + 348 + 234 + 563 + 197 + 26 + 94 + 84 = 2070$$

$$MA = 553 + 479 + 234 + 625 + 351 + 26 + 108 + 84 + 67 + 242 = 2769$$

$$MB = 524 + 348 + 441 + 563 + 197 + 151 + 94 + 175 + 269 + 43 + 123 + 36 = 2964$$

$$IS_{MO} = \frac{2(2070)}{2769 + 2964} = .72 \times 100 = 72\%$$

Table 6.—*Example of high similarity between a revegetated area and a reference area as compared by Motyka and others' and Bray and Curtis' version of Sorensen's index and Spatz' version of Jaccard's index (lbs/acre = dry weight)*

Life form	Revegetated area		Reference area	
	lbs/acre	Percent composition	lbs/acre	Percent composition
Annual grass	187	15	28	2
Perennial cool season bunchgrass	361	29	503	36
Perennial warm season bunchgrass	274	22	391	28
Perennial warm season rhizomatous grass	162	13	154	11
Annual herbs	199	16	14	1
Perennial herbs	62	5	196	14
Biennial herbs			28	2
Broadleaf deciduous shrubs			84	6
Total	1,245	100	1,398	100

Motyka and others' version of Sorensen's index:

$$IS_{MO} = \frac{2\,MW}{MA + MB}$$

$$MW = 28 + 361 + 274 + 154 + 14 + 62 = 893$$

$$MA = 187 + 361 + 274 + 162 + 199 + 62 = 1245$$

$$MB = 28 + 503 + 391 + 154 + 14 + 196 + 28 + 84 = 1398$$

$$IS_{MO} = \frac{2(893)}{1245 + 1398} = 0.68 \times 100 = 68\%$$

Bray and Curtis' version of Sorensen's index:

$$IS_{BC} = MW(\text{percent})$$

$$MW = 2 + 29 + 22 + 11 + 1 + 5 = 70$$

$$IS_{BC} = 70(\text{percent}) = 70\%$$

Spatz' version of Jaccard's index:

$$IS_{SP} = R \times \frac{MC}{MA + MB + MC} \qquad IS_{SP} = 0.37 \times \frac{192}{200} \times 100 = 36\%$$

$$R = \frac{2 - 15 + 29 - 36 + 22 - 28 + 11 - 13 + 1 - 16 + 5 - 14}{8}$$

$$= \frac{0.13 + 0.80 + 0.79 + 0.85 + 0.06 + 0.36}{8} = 0.37$$

Table 7.—*Example of low similarity between a revegetated area and a reference area as compared by Motyka and others' and Bray and Curtis' version of Sorensen's index and Spatz' version of Jaccard's index (lbs/acre = dry weight)*

Life form	Revegetated area		Reference area	
	lbs/acre	Percent composition	lbs/acre	Percent composition
Annual grass	373	25	28	2
Perennial cool season bunchgrass			483	37
Perennial warm season bunchgrass	194	13	345	26
Perennial warm season rhizomatous grass	448	30	148	11
Annual herbs	433	29	13	1
Perennial herbs	45	3	188	14
Biennial herbs			27	2
Broadleaf deciduous shrubs			80	6
Total	1,493	100	1,312	99

Motyka and others' version of Sorensen's index:

$$IS_{MO} = \frac{2\,MW}{MA + MB}$$

$$MW = 28 + 194 + 148 + 13 + 45 = 428$$

$$MA = 373 + 194 + 448 + 433 + 45 = 1493$$

$$MB = 28 + 483 + 345 + 148 + 13 + 188 + 27 + 80 = 1312$$

$$IS_{MO} = \frac{2(428)}{1493 + 1312} = 0.30 \times 100 = 30\%$$

Bray and Curtis' version of Sorensen's index:

$$IS_{BC} = MW(\text{percent})$$

$$MW = 2 + 13 + 11 + 1 + 13 = 30$$

$$IS_{BC} = 30(\text{percent}) = 30\%$$

Spatz' version of Jaccard's index:

$$IS_{SP} = R \times \frac{MC}{MA + MB + MC} \times 100 \qquad IS_{SP} = 0.15 \times \frac{155}{200} \times 100 = 12\%$$

$$R = \frac{2 - 25 + 13 - 26 + 11 - 30 + 1 - 29 + 3 - 14}{8}$$

$$= \frac{0.08 + 0.5 + 0.37 + 0.03 + 0.21}{8} = 0.15$$

APPENDIX IV. SELECTION OF IMPORTANCE VALUES

The selection of importance values for use with rank correlation tests, diversity indices, or similarity indices deserves careful consideration. Production/standing crop is normally the best measure of a species' importance; it indicates both the species' biological activity and the amount of the communities' resources that a species utilizes. The measure has little ambiguity due to collection methods and is directly comparable between species. Density, however, is an inappropriate measure in many communities because of the huge differences in the contribution of individuals of different life-forms (trees versus herbs) to the structure and function of the community. When the community is comprised primarily of one life-form, such as shrubs, then density may be an appropriate importance measure. The determination of a meaningful cover value to express importance may be difficult in multilayered communities. It is best to restrict the use of cover in the calculation of importance value to fairly open communities with a very few layers.

Chambers, Jeanne C. Measuring species diversity on revegetated surface mines: an evaluation of techniques. Res. Pap. INT-322. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 15 p.

Three commonly used measures of plant species diversity are reviewed: (1) diversity indices, (2) rank correlation coefficients, and (3) similarity indices. The suitability of each type of measure for assessing species diversity on mined lands is evaluated and applications of the Shannon-Weiner diversity index, Spearman's rank order correlation coefficient, Motyka and others' and Bray and Curtis' version of Sorensen's similarity index and Spatz' version of Jaccard's index are presented. Of the three types of diversity measures evaluated, only similarity indices allow direct comparisons of two different communities and are sensitive to change in species or life form identities. They can be used with either life form or species data and with different types of importance measures. Similarity indices also permit the development of a standard of comparison.

KEYWORDS: revegetation, species diversity, diversity indices, rank correlation tests, similarity coefficients

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